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BY

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THE RELATION OF ATMOSPHERIC HUMIDITY TO THE DETERIORATION OF EVAPORATED APPLES IN STORAGE[1]

By Charles W. Culpepper, *Associate Physiologist*, and Joseph S. Caldwell, *Physiologist, Office of Horticulture, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

One of the most serious problems encountered in connection with the drying of fruits and vegetables is that of deterioration in storage. Various fruits and vegetables behave differently in this respect as a result of a variety of causes. The wide differences in chemical composition of the materials, as in water content, nature and amount of carbohydrate and protein, acidity, tannin content, presence or absence of fats and essential oils, and enzyme content, are responsible for some of the diversity. The differences in treatment given the material in preparation for drying and in the conditions during the drying of the various products are also factors productive of differences in the subsequent behavior of dried materials in storage. Since there are no defined standards for moisture content in the various products, except in the case of evaporated apples, various lots of any given product usually vary considerably in moisture content, not only when stored in bulk prior to packing but also in the final package. In consequence such materials show differences in rate and character of the changes occurring in storage when held under uniform conditions. On the other hand, a product prepared under carefully controlled conditions develops wide differences in appearance, market grade, and palatability, as a result of storage under varied conditions.

With any given dried product the storage factors which are of particular importance are humidity, temperature, and the readiness with which oxygen can gain access to the material. In the case of dried fruits the humidity of the storage chamber and the initial moisture content of the material are factors of outstanding importance in the control of deterioration in storage.

REVIEW OF LITERATURE

Very little work on the deterioration of evaporated fruits and vegetables under controlled conditions is to be found in the literature.

McGillivray (*8*)[2] reported results of studies on moisture content of evaporated apples extending over a number of years. Commercially packed fruit with a content of moisture in excess of 27 per cent at time of boxing in practically every case showed fermentation within six weeks after packing. Experimental packs of fruit having 27 per cent moisture content were placed in cold storage for 16

[1] Received for publication Aug. 15, 1927; issued December, 1927.
[2] Reference is made by number (italic) to "Literature cited," p. 905.

months. At the end of that time the moisture content had risen to 34.3 per cent and the material was in considerable part decayed. Similar boxes stored in an office room meanwhile lost considerable weight. When opened, restored to the original weight by sprinkling with sterile water, and repacked, such packages invariably underwent fermentation. This result led McGillivray to condemn very strongly the practice of adding water to dry stock in packing as invariably productive of spoilage. His work led to the adoption of 25 per cent as the permissible moisture content of evaporated apples in Canada.

Prescott, Nichols, and Powers (*12*) conducted investigations of the spoilage of dehydrated vegetables under various conditions of storage. They isolated a large number of species of bacteria and mold fungi, mainly of the commoner soil forms. Storage in very dry air, at either high or low temperatures, resulted in great reduction in the number of bacteria present. At humidities above 70 per cent and temperatures of 20° to 25° C. various vegetables which had been dried to a residual moisture content of 4 per cent absorbed sufficient moisture from the atmosphere during 7 to 10 weeks of storage to permit rapid development of mold colonies. These investigators concluded that evaporated vegetables could be safely stored only in air-tight containers.

Gore and Mangels (*5*) found that when turnips, onions, spinach, and cabbage were dried without previous cooking and stored in sealed glass jars in the dark at 70° to 90° F., the moisture content of the material had to be reduced to 5 per cent in order to preserve odor and color unchanged for six months. With moisture content above this limit, darkening, loss of distinctive odor, and development of distinctly unpleasant odors occurred.

Nichols (*9*) states that "active spoilage" (evidently referring to visible growth of molds) in leaf vegetables such as spinach occurs when the moisture content has reached about 20 per cent, and that starchy and sugary vegetables and fruits generally do not show such spoilage until a moisture content of 25 to 30 per cent has been reached. Enzymic darkening occurred when the moisture content was above 10 per cent but was arrested when moisture was reduced to 5 per cent. Nichols, Powers, Gross, and Noel (*10*) conclude that "to assure best keeping qualities the moisture content of fruits containing much sugar should not exceed 15 to 20 per cent, while that of other fruits and vegetables should not exceed 5 to 10 per cent, the preference in both cases being for the lower percentage." They emphasize the necessity for employing sealable moisture-proof packages for such products.

Cruess, Christie, and Flossfeder (*2*) and Cruess and Christie (*1*) state that grapes dried to 23 per cent moisture after sulphuring will keep indefinitely, but that those with higher moisture contents ultimately mold, as do prunes with more than 25 per cent moisture. Lewis, Brown, and Barss (*7*) state that in their experimental work with prunes they have adopted 17 to 18 per cent as the proper moisture content, but that in some cases it ran as high as 22 per cent without apparent injury to keeping quality.

It is obvious that in some cases the differences in quantities of residual moisture considered safe by different workers are attributable

to differences in climatic conditions under which the experimental work was done, as in the recommendations for prunes just cited. Despite such minor differences, all workers agree that safety in prolonged storage requires drying of all products to somewhat lower moisture contents than are generally employed in commercial practice.

EXPERIMENTAL WORK

The present work was undertaken for the purpose of studying the effect of humidity of the storage room as a factor in the deterioration of dried fruits. Of the various important dried fruits, evaporated apples probably undergo most rapid decline in appearance and quality when stored for considerable periods, despite the fact that a definite limit of moisture content of 24 per cent is prescribed by Food Inspection Decision 176 (*6*). Consequently it was determined to study in some detail the relation of humidity to the changes occurring in this product in storage.

MATERIAL AND METHODS

The fruit employed was grown in the variety orchard of the Office of Horticulture at the Arlington Experiment Farm, Rosslyn, Va. Five varieties—Ben Davis, Delicious, Rome Beauty, Winesap, and Yellow Transparent—were used. These were chosen by reason of their differences in chemical composition and in color and texture of flesh. Four of the five are employed in some quantity in the commercial production of evaporated apples. Yellow Transparent, which is not used in commercial drying, was also used for the reason that it differs considerably in composition from the others. It is a white-fleshed, soft-textured summer variety, high in acid and astringent content, low in sugar and total solids, and has little distinctive flavor. Ben Davis is a coarse-fleshed white variety, rather low in sugar content for a variety of its season, medium in acidity and astringency, and has little distinctive flavor. Delicious is a yellow-fleshed variety of medium sugar content, low in astringency and exceptionally low in acid content, and has a highly distinctive flavor. Rome Beauty has flesh slightly tinged with yellow, a medium sugar content, low acidity, and a fairly pronounced and characteristic flavor. Winesap has a somewhat yellow, fine-grained flesh, high in sugar content, is of medium acidity and astringency, and has a distinctive flavor.

No analyses of the whole fruits were made, but portions of the same lots were pressed for juice making, and analyses of the freshly expressed juices were made. The results of these analyses, which convey an idea of the particular lots of fruit employed, are recorded in Table 1.[8]

[8] The volumetric permanganate method was employed in determining free reducing sugars and total sugars after acid hydrolysis. Acidity was determined by titration with N/10 sodium hydroxide against phenolphthalein, the results being calculated as malic acid. Total and nontannin astringency were determined by the Loewenthal-Procter method. Total solids were determined by drying portions of the fresh juice to moist dryness on a water bath and bringing to constant weight in a vacuum oven at 80° C. Hydrogen-ion concentrations were made by the use of the Bailey hydrogen electrode, and were checked with the quinhydrone electrode.

TABLE 1.—*Chemical composition of freshly expressed juices of apple material used in storage experiments*

Variety	Constituents (per cent)								
	Acid as malic	Reducing sugar	Cane sugar	Total sugar	Total astringency	Tannins	Non-tannins	Total solids	Hydrogen-ion concentration
Ben Davis	0.520	6.32	3.42	9.74	0.924	0.436	0.488	13.44	3.40
Delicious	.279	9.00	1.10	10.10	.868	.377	.491	12.46	4.02
Rome Beauty	.360	6.62	3.79	10.41	.817	.204	.613	12.89	3.54
Winesap	.520	8.40	4.61	13.01	.859	.430	.429	15.07	3.43
Yellow Transparent	.680	6.84	1.06	7.90	1.942	1.125	.817	9.23	3.36

The fruit used was a portion of the tree-run crop of the varieties harvested when commercially picking ripe and was delivered to the laboratory as soon as picked. It was stored in a basement room until it had reached firm eating-ripe condition. A considerable quantity of each variety was then peeled, cored, and sliced by machine, and the sliced fruit was divided into four portions. One lot was immediately placed in the evaporator without further treatment. A second lot was spread on drying trays and heated to 80° C. (176° F.) for 15 minutes by placing in a closed chamber heated by steam jets placed beneath the trays, then transferred to the evaporator. A third lot was dipped into 2 per cent cold sodium chloride solution for 10 to 15 seconds before spreading on the drying trays, and a fourth lot was exposed on trays to the fumes of burning sulphur in a closed chamber for 30 minutes. All were dried together in a tunnel evaporator at a temperature of approximately 60° to 65° C. (140° to 149° F.).

The four treatments described, when applied to fruit of the five varieties employed, yielded material showing a very wide range in appearance and color as it was taken from the evaporator. The material which received no treatment prior to drying showed considerable brown discoloration at the surface of the slices as a result of oxidations during drying. This was much more pronounced in Yellow Transparent than in the other varieties. The untreated lots in all varieties were distinctly superior to the others in flavor, but considerably less attractive in appearance and color. The material treated with sulphur dioxide was the most attractive in appearance, as it showed no browning or other discoloration. The color was a bright light yellow in Ben Davis and Yellow Transparent and a slightly deeper golden yellow in Delicious, Winesap, and Rome Beauty. The flavor of the sulphured material was very good but scarcely equal to that of the untreated material.

The material treated with sodium chloride was much whiter than that receiving any other treatment, but had a peculiar grayish-white tint. Occasional pieces had a very faint pink discoloration, especially noticeable in Yellow Transparent and Winesap. The flavor was distinctly inferior to that of the sulphured material, but the slight saltiness of this fruit made comparison of the two lots somewhat difficult.

The material heated to 80° C. (176° F.) in a current of steam was considerably brighter in color than untreated material, but much

less attractive in appearance than that treated with sulphur fumes or sodium chloride. Many of the slices collapsed during the drying, becoming thin and semitransparent and adhering firmly to the drying trays. The material was distinctly lacking in the richness and fullness of flavor possessed by the untreated material, but was superior in this respect to that which had been dipped in sodium chloride.

All the lots of fruit were allowed to remain in the evaporator until the pieces contained approximately 15 per cent of moisture. The samples used in the storage experiment consisted of 100 gm. each in one series and 200 gm. in another, and were weighed out in a tared dish and immediately transferred to muslin bags and placed in the storage chambers. Three to five identical samples were prepared from each lot of fruit, in order to permit withdrawal of samples for examination and determination of moisture content at intervals during the experiment.

The storage chambers consisted of tall bell jars of 11,000 c. c. capacity, held in inverted position by suitable supports and covered by heavy glass plates made air-tight by stopcock grease. Atmospheric humidities ranging from 88.8 to 8.5 per cent by steps of approximately 10 per cent were obtained by placing in each of the chambers a comparatively large quantity (1,850 c. c.) of sulphuric acid solution of the proper concentration. The series was completed by adding two chambers, one containing calcium oxide, the other distilled water. This gave a series of 10 chambers having relative humidities respectively of 0, 8.5, 18.8, 37.1, 47.7, 58.3, 70.4, 80.5, 88.8, and 100 per cent.

The samples of fruit were loosely packed into small muslin bags, and the bags placed on perforated porcelain plates supported at some distance above the level of the liquid in the chambers. Care was taken to arrange the bags so that free access of air to all the samples was not restricted. The purpose of the experiment was to simulate the conditions prevailing in fruit stored loosely in bulk, and not those in material packed in final containers.

The series of chambers were placed in an insulated room kept at a constant temperature of 25° C. (77° F.) for the first 12 months of storage, after which it was necessary to transfer them to a laboratory room in which the seasonal fluctuations of temperature ranged between 20° and 30° C. (68° and 86° F.). Since it was possible to employ only one controlled temperature, that chosen was made to approximate the maximum temperatures encountered in common storage. Temperature is a factor of considerable importance in determining the rate of deterioration, so that the rate and extent of deterioration here observed would not be expected to hold in experiments carried on at other temperatures.

The material was examined at intervals of one to two weeks during the first two or three months of storage and at longer intervals thereafter. Detailed notes were made at each examination as to any discoverable changes in appearance, color, and market grade of the material, and at intervals of three or four months one of the duplicate samples of each lot was removed and employed for a determination of moisture content after any changes in color, odor, flavor, and palatability had been determined.

CHANGES IN APPEARANCE AND PALATABILITY

Alteration in appearance was rather promptly apparent in the fruit in the chambers having high humidities. In the chamber with saturated atmosphere a slight brownish discoloration could be observed in the material after 10 days, and this continued to deepen until all the material was uniformly dark brown in color. This change occurred somewhat less rapidly in the material treated with sulphur dioxide than in that receiving other treatments, but at the end of six to eight weeks the sulphured material was indistinguishable from the other lots. Of the five varieties employed, Yellow Transparent showed discoloration earlier than the others and also developed it somewhat more rapidly.

In the chamber with 88.8 per cent humidity the changes were in all respects identical, with the single difference that they appeared a little later and developed somewhat more slowly. As the material from the series of chambers was examined the alteration in color became less and less evident until a point was reached at which no change in color was apparent. After six weeks' storage this point of no change was reached in the chamber having 70.4 per cent relative humidity, but with continuation of the storage period it shifted to a lower humidity, as indicated in Tables 2 and 3.

Concurrently with the changes in color, alterations in the moisture content, odor, and flavor of the material began to appear. Even at the end of 10 days it was apparent that the material in 100, 88.8, and 80.5 per cent humidity was gaining in weight through absorption of moisture, and this became increasingly apparent in these lots at subsequent examinations. At the end of six weeks the development of mold colonies was evident on occasional slices in all but the sulphured lots in the saturated atmosphere, and the odor of incipient fermentation was apparent on opening both the 100 per cent and the 88.8 per cent chambers. A slightly bitter flavor was apparent in the material dried without any treatment and kept in 100 and 88.8 per cent humidity. These changes became less evident in passing down the scale of humidity, the material in the 70.4 per cent chamber having undergone no discoverable change in color, odor, or flavor, and little if any change in moisture content at the end of six weeks.

In the case of the lots stored at humidities less than 70.4 per cent, it was apparent after six weeks that loss of moisture had occurred in quantities proportional to the relative humidities of the various chambers, but the odor, flavor, and color of the material was unchanged.

In the interval between the sixth and sixteenth weeks of storage, the changes occurring may be summarized as consisting of the appearance of some degree of discoloration in the chambers having 70.4, 58.3, and 47.2 per cent humidity, in the order named, followed by the development of a musty, unpleasant odor and, in the case of the material at higher humidities, of a noticeable alteration in taste. In the 100 and 88.8 per cent chambers absorption of moisture and continued growth of molds and yeasts converted the material within the bags to soggy, decaying masses having a strong odor of fermentation.

TABLE 2.—*Condition of evaporated Yellow Transparent apples after 112 days' storage at various humidities*

Humidity	Treatment	Presence of molds	Taste	Odor or flavor	Color	General appearance	Grade
Saturation	Untreated	Abundant	Bitter, rancid	Musty, fermenting	Dirty brown	Very poor	Unmarketable.
Do	SO^2	do	do	do	Very brown	do	Do.
Do	NaCl	do	do	do	do	do	Do.
Do	Steam	do	do	do	Dirty brown	do	Do.
88.8 per cent	Untreated	Small quantity	do	Very musty	Very brown	do	Do.
Do	SO^2	do	do	do	do	do	Do.
Do	NaCl	do	do	do	do	do	Do.
Do	Steam	do	do	do	do	do	Do.
80.5 per cent	Untreated	Occasional	Bitter, stale	do	do	do	Do
Do	SO^2	do	do	do	do	do	Do.
Do	NaCl	do	do	do	do	do	Do.
Do	Steam	do	do	do	do	do	Do.
70.4 per cent	Untreated	None	Somewhat stale	Old sugar-barrel odor	do	do	Do.
Do	SO^2	do	do	do	do	do	Do.
Do	NaCl	do	do	do	do	do	Low prime.
Do	Steam	do	do	do	do	do	Unmarketable.
58.3 per cent	Untreated	do	do	do	do	do	Scarcely marketable.
Do	SO^2	do	do	do	do	Medium	Good prime.
Do	NaCl	do	do	do	do	do	Prime.
Do	Steam	do	do	do	do	Poor	Low prime.
47.2 per cent	Untreated	do	A little stale	Somewhat abnormal	do	Medium	Do.
Do	SO^2	do	do	do	Light brown	Good	Good prime.
Do	NaCl	do	do	do	Grayish brown	Medium	Do.
Do	Steam	do	do	do	do	Poor	Low prime.
37.1 per cent	Untreated	do	Fair	Almost normal	do	Medium	Do.
Do	SO^2	do	do	do	Light brown	Good	Good prime.
Do	NaCl	do	do	do	Grayish brown	Medium	Do.
Do	Steam	do	do	Very good	do	do	Low prime.
18.8 per cent	Untreated	do	Fairly good	do	do	Good	Do.
Do	SO^2	do	do	do	Bright light yellow	Bright light color	Good prime
Do	NaCl	do	do	do	Grayish pink	Medium	Do.
Do	Steam	do	Fair	do	Light brown	Fair	Do.
8.5 per cent	Untreated	do	Good	do	do	Good	Do.
Do	SO^2	do	do	do	Bright light yellow	Very good	Choice.
Do	NaCl	do	Fair	do	Somewhat pink; grayish	Fair	Prime.
Do	Steam	do	do	do	Somewhat brown	Good	Good prime.
Completely dry	Untreated	do	do	do	do	do	Prime.
Do	SO^2	do	do	do	Bright light yellow	do	Good prime.
Do	NaCl	do	do	do	Grayish	Fair	Do.
Do	Steam	do	do	do	Light brown	Good	Do.

TABLE 3.—*Condition of evaporated Rome Beauty apples after 112 days' storage at various humidities*

Humidity	Treatment	Presence of molds	Taste	Odor or flavor	Color	General appearance	Grade
Saturation	Untreated	Present	Stale, acid rancidity.	Very musty	Very dark brown	Very poor	Unmarketable.
Do	SO_2	do	do	do	do	do	Do.
Do	NaCl	do	do	do	do	do	Do.
Do	Steam	do	do	do	do	do	Do.
88.8 per cent	Untreated	Small amount	Very stale	do	Dark brown	do	Do.
Do	SO_2	do	do	do	do	do	Do.
Do	NaCl	do	do	do	do	do	Do.
Do	Steam	do	do	do	do	do	Do.
80.5 per cent	Untreated	Occasional	Stale	Old sugar-barrel odor	Brown	Poor	Scarcely marketable.
Do	SO_2	do	do	do	do	do	Low prime.
Do	NaCl	do	do	do	do	do	Do.
Do	Steam	do	do	do	do	do	Scarcely marketable.
70.4 per cent	Untreated	None	do	do	do	do	Do.
Do	SO_2	do	do	do	do	Medium	Do.
Do	NaCl	do	do	do	[illegible]ght brown	do	Low prime.
Do	Steam	do	do	do	[illegible]wn	Poor	Marketable.
58.3 per cent	Untreated	do	Somewhat stale	Somewhat abnormal	do	Medium	Low prime.
Do	SO_2	do	do	do	Light brown	Fair	Prime.
Do	NaCl	do	do	do	Pinkish brown	Poor	Do.
Do	Steam	do	do	do	Brown	do	Low prime.
47.2 per cent	Untreated	do	Fair	Fair	do	Medium	Do.
Do	SO_2	do	do	do	Slightly brown	Fair	Good prime.
Do	NaCl	do	Poor	do	Grayish pink	Poor	Prime.
Do	Steam	do	do	do	Somewhat brown	do	Low prime.
37.1 per cent	Untreated	do	Excellent	Good	do	Fair	Prime.
Do	SO_2	do	do	do	Light yellow	Excellent	Good choice.
Do	NaCl	do	Fair	do	Grayish pink	Abnormal	Prime.
Do	Steam	do	Good	do	Somewhat brown	Poor	Do.
18.8 per cent	Untreated	do	Excellent	Very good	do	Fair	Do.
Do	SO_2	do	do	do	Bright, light yellow	Excellent	Fancy.
Do	NaCl	do	Fair	do	Pinkish	Abnormal	Choice.
Do	Steam	do	Good	do	Slightly brown	Fair	Do.
8.5 per cent	Untreated	do	Excellent	do	Somewhat brown	Good	High prime.
Do	SO_2	do	do	do	Bright, light yellow	Excellent	Extra fancy.
Do	NaCl	do	Fair	do	Rose pink	Somewhat normal	Choice.
Do	Steam	do	Good	do	Slightly brown	Fair	Do.
Completely dry	Untreated	do	Excellent	do	Somewhat brown	Good	High prime.
Do	SO_2	do	do	do	Bright, light yellow	Excellent	Extra fancy.
Do	NaCl	do	Fair	do	Greenish, slightly pink	Fair	Choice.
Do	Steam	do	Good	do	Slightly brown	do	Do.

The condition of the materials in the various chambers at the end of 112 days of storage is stated in summary form for two of the varieties, Yellow Transparent and Rome Beauty, in Tables 2 and 3. The conditions obtaining in the other varieties were so closely identical with those in Rome Beauty that they do not need detailed separate statements, but a few minor differences will be noted in a subsequent paragraph.

In addition to the statements tabulated in Tables 2 and 3 it may be noted that at the end of 112 days of storage all the material stored at humidities of 47.2 per cent or higher had become rather uniformly brown, regardless of the nature of the treatment given prior to drying. Thus the material treated with sulphur dioxide, while not developing discoloration as early as the other lots, at the end of this time had become indistinguishable from the fruit receiving no treatment prior to drying.

At relative humidities lower than 47.2 per cent there was progressive improvement in color with decrease in the atmospheric moisture of the storage chamber in the case of the sulphured material, and at 18 per cent humidity or less there was no change in color. Untreated material was distinctly browned at all humidities above 18 per cent, while that which had been steamed prior to drying was also browned, but to a lesser degree than untreated material. The material dipped in sodium chloride solution was indistinguishable from that receiving other treatments in the case of the lots stored at higher humidities, but in the material held at lower humidities a distinctly pinkish coloration was present. This was not observed except in material treated with sodium chloride, but it was present in all such material stored in relatively dry air. In the case of Yellow Transparent this pink coloration was first observable in the fruit held at 37.1 per cent humidity and was most pronounced in that held at 18.1 per cent. In the other varieties it was detectable in the salt-treated material held at 58.3 per cent as a pinkish tinge along the core line and about the vascular bundles of the slices. In material held at 47.2 per cent humidity all the slices were grayish pink at the surfaces but showed a central zone of normal color when cut across. The pink discoloration was still more pronounced in material held at 37.1 per cent and was present in decreasing degree in the material held at lower percentages of atmospheric moisture. The fruit of the different varieties differed somewhat in that the pink color was more pronounced in those which had whitest flesh.

It would appear probable that this pink discoloration is the result of reaction of the absorbed sodium chloride with some constituent of the apple flesh, probably a flavone or tannin. Whatever the nature of the reaction responsible for the development of the pink color, it is peculiar in that the color is most strongly developed in an atmosphere having 18 to 37 per cent relative humidity and decreases in intensity with either increase or decrease in humidity of the storage room. This type of discoloration has been observed by one of the writers in apples evaporated after dipping in sodium chloride and subsequently stored in a very dry atmosphere, and also in overdried commercial evaporated apples which had been salt dipped prior to drying, but it does not seem to have been mentioned in the literature.

From the results obtained with the use of sulphur dioxide and sodium chloride it may be concluded that these agents are effective in

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preventing brown discoloration during the drying process, but that the effect is temporary in character. Neither of these agents prevents a gradual browning of the tissues, which ultimately appears in storage, although sulphur dioxide delayed its appearance somewhat longer than sodium chloride under the conditions of these experiments. This is in general agreement with the results of Overholser and Cruess (*11*) on the effectiveness of these treatments in preventing discoloration in apple juices. Those authors did not investigate the effect of prolonged storage.

The effects of varying degrees of humidity upon changes in odor and flavor of the fruit were of about the same order as the effects upon alteration of color, as indicated in Tables 2 and 3, but developed more slowly. All the samples held at humidities lower than 80.5 per cent remained normal in odor and taste during the first six weeks of storage. Those at higher humidities developed colonies of molds and were markedly abnormal in odor and taste. At the end of 112 days all samples at humidities higher than 70.5 per cent had developed a distinctly bitter, unpleasant taste and an odor strongly suggestive of barrels in which moist, unrefined sugar had been stored. These abnormalities in odor and flavor were perceptible in samples in which no visible growth of mold or other organisms had occurred, as in some of the lots from the 80.5 and 70.4 per cent chambers. In the lots held at humidities below 70.4 per cent, odor and taste became progressively more nearly normal with decreasing humidity, and at a humidity of 37 per cent or less no detectable change had occurred.

Yellow Transparent differed somewhat markedly from the other varieties in that it showed greater alteration in color, odor, and flavor under any given condition than did the other varieties. In other work it has been observed that most early apples of the low-sugar, high-acid types are much like Yellow Transparent, deteriorating rapidly in storage. This fact is familiar to many operators of commercial evaporators, who base their refusal to employ early maturing varieties upon the impossibility of preserving the appearance and quality of the material for more than very short periods.

The behavior of Ben Davis, Delicious, Winesap, and Rome Beauty with respect to alteration in color, odor, and flavor under the various conditions of storage was so closely identical that details with respect to Rome Beauty (Table 3) are fairly representative of the group. The fall and winter varieties, with their relatively higher sugar content, are much better preserved in storage than is Yellow Transparent. The relatively low sugar content and the high tannin content of the variety last named appear to offer conditions favorable to rapid oxidation and other changes involved in deterioration in spite of its higher total and actual acidity.

That hydrogen-ion concentration may be an important factor in controlling the rate of action of oxidase is indicated by the work of Overholser and Cruess (*11*), who found that in apple juice darkening on exposure to air was progressively lessened by progressively increasing additions of hydrochloric acid. Falk, McGuire, and Blount (*4*) also found that in potatoes and certain other vegetables, both fresh and dehydrated, the activity of oxidase and peroxidase was progressively inhibited by increasing acidity of the medium. In the present work deterioration was most rapid and greatest in the variety having highest total acidity and hydrogen-ion concentration. This

may indicate that these changes are not produced by enzymes; if they are, other factors outweigh the effect of acidity.

Certain consistent minor differences in the behavior of the dried product made from the different winter varieties which were noted in the course of the work are of sufficient interest to warrant brief statement. At any given degree of humidity, the material of Delicious was invariably darker in color, more abnormal in odor and flavor, and showed more extensive growth of molds, where molds were present, than did samples of Winesap and Ben Davis given identical treatments and stored under the same conditions. Rome Beauty like Delicious showed much greater change in color under given conditions than did Winesap and Ben Davis, but differed in that odor and flavor were as well preserved as in the latter varieties. At the lower humidities, fruit of Delicious and Rome Beauty which had been salt dipped prior to drying showed distinctly less pink discoloration than did salt-dipped Ben Davis or Winesap from the same storage chambers. The behavior of Rome Beauty differed in one respect from that of all the others, in that the brown discoloration developed at the higher humidities was invariably reddish brown, as contrasted with the light to dark brown, without admixture of red, seen in the other varieties. Much more extended work would be necessary to determine whether these differences are constant for the varieties.

FURTHER CHANGES ON EXTENSION OF THE STORAGE PERIOD

As indicated in Tables 2 and 3, the material kept in atmospheric humidities of 100 and 88.8 per cent had been so far altered after 112 days' storage as to be unpalatable and unmarketable. These lots were consequently discarded after samples had been taken for determination of moisture content. The experiment was continued with the remaining chambers, which were held in a room having a constant temperature of 25° C. (77° F.) for one year, then transferred to a room in which the temperatures ranged from 20° to 30° C. (68° to 86° F.) with changes in the season, and there held for a further period of two years and three months. The chambers were opened from time to time for inspection and the making of notes as to condition of the material.

There were no further rapid changes in appearance and color of the material. The lots in atmospheres having humidities of 80.5 to 47.2 per cent underwent a slow, progressive darkening in color, which was most rapid in rate and greatest in degree in the chamber having greatest moisture content and decreased in rate and degree with decrease in humidity of the air present. In the higher humidities there was progressive alteration of odor and flavor, the bitterness and objectionable odor observed earlier in the material stored in approximately saturated atmospheres becoming more and more apparent with the passage of time. These changes were not conditioned upon the development of molds, since they occurred in the absence of any visible growth of organisms. In the chambers having humidities of 37.1 per cent or less the material remained in perfect condition in respect of color, appearance, odor, and flavor, except in the case of Yellow Transparent. In that variety perceptible browning had occurred even in the chamber having 8.5 per cent humidity,

and only the samples held over calcium oxide retained their original color after more than three years.

The experiment was discontinued at the end of three years and three months, when detailed final notes were taken and determinations of moisture content made upon all the lots of material. Minor differences in the several varieties were noted, but these were of the character already described.

MOISTURE CONTENT ATTAINED BY THE MATERIAL AT VARIOUS HUMIDITIES

The moisture-absorbing or water-holding capacity of the material at various degrees of humidity is of particular interest. The moisture content of the various lots of material varied slightly when they were placed in the humidity chambers, but closely approximated 15 per cent. As the material gained or lost in weight the sulphuric-acid solutions became more concentrated or more dilute, with a resulting alteration of the humidity of the chamber from its original calculated content. An error was thus introduced, but the quantity of acid used in each chamber was purposely made large enough to reduce the error to a small value, which was further reduced by replacing the acid after the first 8 or 10 weeks of storage.

Moisture determinations were made by weighing out 50 to 100 gm. of the sample and drying to constant weight at 80° C. in a vacuum oven. Table 4 shows the result of the moisture determinations made at the end of the storage period of three years and three months for the samples held in the lower humidities (70.4 per cent or less) and at the end of shorter periods for those in the higher humidities.

The data for the samples in the high humidity chambers (Table 4) are incomplete for two reasons. Many of the samples showed such extensive attack by molds and yeasts that large losses of sugar had occurred. Such samples were weighed to the nearest gram as they were removed from the chambers, no attempt at more accurate determinations being made. Those showing less extensive attack by organisms were sampled for weighing, but some of the samples were destroyed by accident before final weighings were obtained. The crude weighings show sufficiently close agreement with the figures given in the table to make it certain that these figures are truly representative of the condition of the material in these chambers as regards its water content.

TABLE 4.—*Moisture content of evaporated apples of different varieties held in atmospheres of various humidities after attainment of equilibrium* [a]

Humidity	Treatment	Moisture content (per cent)				
		Yellow Transparent	Rome Beauty	Winesap	Delicious	Ben Davis
Saturation	Untreated	54.31	55.46	—	—	—
Do	Steam	—	—	—	—	51.74
Do	NaCl	—	56.31	—	—	—
Do	SO_2	—	—	55.23	—	—
88.8 per cent	Untreated	33.35	35.18	—	36.57	42.04
Do	Steam	—	—	—	—	40.38
Do	NaCl	—	—	43.23	44.66	42.00
Do	SO_2	—	—	—	46.99	42.25
80.5 per cent	Untreated	26.56	25.78	25.35	—	28.63
Do	Steam	—	—	24.54	—	27.70
Do	NaCl	—	27.03	26.76	—	29.38
Do	SO_2	—	24.93	23.20	25.59	27.36
70.4 per cent	Untreated	23.42	20.19	19.27	17.65	20.42
Do	Steam	—	19.06	19.00	—	18.66
Do	NaCl	—	21.28	21.12	22.21	21.18
Do	SO_2	—	20.59	20.22	21.59	19.73
58.3 per cent	Untreated	13.69	14.38	13.28	13.74	13.25
Do	Steam	13.90	13.31	13.00	—	13.58
Do	NaCl	14.85	14.81	14.12	13.74	14.75
Do	SO_2	13.57	14.24	15.36	12.82	14.27
47.2 per cent	Untreated	9.79	9.66	9.50	6.62	9.90
Do	Steam	8.64	8.92	9.00	—	8.76
Do	NaCl	10.97	10.21	10.26	11.33	10.70
Do	SO_2	8.84	—	8.47	10.80	10.02
37.1 per cent	Untreated	7.59	7.67	7.76	6.97	6.20
Do	Steam	7.00	6.34	6.57	—	6.51
Do	NaCl	8.22	7.77	7.45	5.83	7.24
Do	SO_2	7.62	7.74	7.00	7.14	6.71
18.8 per cent	Untreated	4.80	3.87	3.61	2.36	2.95
Do	Steam	3.78	2.69	3.10	—	2.02
Do	NaCl	4.66	4.03	3.85	2.94	2.26
Do	SO_2	3.80	4.03	3.56	2.39	2.61
8.5 per cent	Untreated	2.42	.15	1.97	.61	.89
Do	Steam	1.57	.11	1.60	—	.85
Do	NaCl	2.44	.11	1.80	.33	—
Do	SO_2	1.78	.57	2.01	.32	.63
Completely dry	Untreated	.40	.53	.47	.74	1.04
Do	Steam	.41	.16	.63	—	1.04
Do	NaCl	.35	.65	.68	.66	.96
Do	SO_2	.46	.04	.91	.83	.72

[a] In the case of the lower humidities (70.4 per cent or less) the weighings were made at the end of three years and three months. In the higher humidities the weights recorded are the last it was possible to obtain before invasion by molds proceeded so far as to invalidate the weighings.

Evaporated apples are very highly hygroscopic, and this property is the initial cause for deterioration. When stored in air of any given degree of humidity, the material, regardless of its original moisture content, comes into equilibrium with the atmosphere by gain or loss of moisture. In the present instance material having an initial moisture content of 15 per cent was practically in equilibrium with an atmosphere of 58.3 per cent relative humidity, as almost no gain or loss in moisture content occurred. With increase in humidity there was a rather uniform increase in moisture content of the material, that in a saturated atmosphere taking up somewhat more than its own weight of water. With humidities below 58.3 per cent there was progressive decrease in moisture content of the material, that stored over calcium oxide becoming nearly water free. As the presence of a certain quantity of water in the material is one of the necessary conditions for the occurrence of deterioration, the samples having less than this quantity show no discoverable changes even on greatly prolonged storage, and those having more than this quantity

show a rate and degree of alteration very definitely related to their water content.

The highly hygroscopic character of desiccated plant material has not always been sufficiently considered, or certainly has not always been adequately emphasized, in making recommendations as to "safe" moisture contents for evaporated products. There is no "safe" moisture content for any such material unless it is at once placed under such conditions that absorption of water vapor from the atmosphere can not occur. Unless this is done, drying to any arbitrarily chosen percentage of moisture, no matter how low, can be expected to preserve the material unchanged only so long as the moisture of the surrounding atmosphere does not rise above the point of equilibrium with the product. If this occurs, water will be absorbed to an extent determined by the humidity and the freedom of access of air to the material, and spoilage may occur. This fact is sufficiently important to warrant the placing of decided emphasis upon it in any consideration of preservation of materials of hygroscopic character by drying.

Some conception of the magnitude of the forces concerned in the absorption and retention of moisture by partially desiccated fruits may be gained from consideration of the fact that evaporated apples with 13 to 15 per cent moisture are in equilibrium with an atmosphere of about 58.3 per cent relative humidity, which is obtained over sulphuric acid of 1.30 specific gravity (40 per cent acid). Over acid of 1.25 specific gravity (33.5 per cent acid) such material absorbs an additional 5.7 per cent of moisture, while over acid of 1.35 specific gravity (45 per cent acid) it gives up an approximately equal amount. The assumption that fruit of 15 per cent moisture content is approximately in equilibrium as respects its moisture-absorbing power with sulphuric acid of 1.30 specific gravity thus appears to be justified. While the osmotic pressures of sulphuric acid in high concentrations can not be accurately determined, as Shull (*14*) has shown, from the use of formulae for "ideal" solutions, calculations by several methods give values ranging from 720 to 798 atmospheres as the osmotic pressure of sulphuric acid of 1.30 specific gravity.

Comparisons of the data on moisture content of material given various treatments prior to drying indicate that such treatments may to some extent affect the water-absorbing capacity of the fruit. That which was dried without treatment and that which had been exposed to sulphur dioxide showed no consistent differences in this respect. That which had been heated to 80° C. in steam rather consistently showed reduced moisture absorption or retention as compared with untreated material, while that dipped in sodium chloride showed somewhat higher moisture absorption, which may be attributed to the salt remaining in and upon the slices.

That the moisture-absorbing capacity of a variety is not directly related to its content is evident from inspection of the data in Tables 1 and 4. Winesap, which is considerably higher in sugar than any of the other varieties, took up smaller percentages of water, especially at the higher humidities, than did the others. Yellow Transparent took up quite as much moisture as any of the others and in a number of cases more, despite its very low content of sugar and total solids. It is evident that the water-absorbing capacity of the several varieties is determined by differences in the character and amount of the

hydrophile colloids present, and that sugar content plays only a minor rôle therein.

A somewhat unexpected outcome of the present work is the discovery that total arrest of deterioration in evaporated apples over prolonged periods can be accomplished only by reducing the moisture content to 8 per cent, as was done in the chamber having 37.1 per cent relative humidity, or a lower figure.

At constant humidities ranging from 47.2 to 80.5 per cent deterioration in color became apparent within a short time and was followed on prolonged storage by development of abnormal, rancid odor and pronounced bitter flavor. At the end of 112 days these changes were well advanced in all the fruit having a moisture content in excess of 18 per cent, and after three years all the material having more than 10 per cent of moisture had become unmarketable if not wholly unfit for consumption. These changes were not accompanied by visible growth of molds or yeasts and occurred under conditions, at least in the lower humidities, which inhibit the growth of these organisms. These changes have been considered as due to the action of enzymes and as being of less importance than those due to molds (*9*). In the apples here used it is questionable whether enzymes are concerned, since they occur in fruit which has been heated to a temperature of 80° C. (176° F.), or in that treated with sulphur dioxide or sodium chloride, to the same degree as in untreated material.

The work of Overholser and Cruess (*11*) indicates that although sulphuring or heating to 80° C. does not inactivate the peroxidase of apple tissue, both treatments destroy the organic peroxide and thus inactivate the oxidizing system. That dilute sodium chloride and other alkali chlorides markedly depress the activity of oxidizing systems is indicated by the work of Ewart (*3*) on the oxidase of apple tissue and by that of Rose, Kraybill, and Rose (*13*) on that of apple bark. If the discoloration of the tissues is the result of enzyme action, the effects of such agents as heat, sulphur dioxide, and sodium chloride upon the oxidizing system are only temporary in character and are followed by ultimate resumption of activity, notwithstanding the continued presence of sulphur dioxide or salt. Furthermore, the action was most rapid in the case of the variety having highest titratable and actual acidity.

Whatever the cause of the darkening in color and the attendant development of abnormal odors and flavors, these changes are less important than those produced by molds and yeasts only in that they occur more slowly, hence require a longer time to reduce the material to unmarketable condition. But they are extremely important, in that they lower the grade and value of the product in which they occur, and are not arrested by bringing the moisture content of the material to a level at which growth of organisms can not occur.

At moisture contents higher than 25 per cent, the deterioration process develops another phase in consequence of the growth and multiplication of organisms which quickly render the material unmarketable and ultimately wholly destroy it.

Adequate protection against deterioration in evaporated apples can be obtained only by taking into consideration the facts in regard to

the two interrelated but independent types of deterioration here described. Temperature is an important factor in determining the rate and extent of deterioration of both types, but the effects of variation in this factor have not been included in this study.

SUMMARY

Evaporated apples of uniform initial moisture content, made from five varieties of rather widely varying types and given four different treatments preparatory to drying, were stored at a temperature of 20° to 30° C. (68° to 86° F.) in atmospheres having humidities ranging from complete saturation to complete dryness for somewhat more than three years, with frequent examination.

The material in all cases either absorbed or gave up moisture until a new moisture content in equilibrium with the moisture of the chamber had been reached.

At relative humidities of 18.8 per cent or less, the material retained its original color, odor, and flavor unchanged throughout the entire storage period. Evaporated apples can be preserved indefinitely by sufficiently reducing the moisture content of both the material and the storage chamber.

At relative humidities between 47 and 80.5 per cent, growth of molds and yeasts did not occur, but the fruit developed progressive brownish discoloration, rancid odor, and abnormal, bitter flavor, which rendered the material unpalatable and unmarketable before the expiration of the storage period. The rate at which these changes occurred increased with increase in humidity throughout the series.

These alterations in color, odor, and flavor became evident within one year in fruit having the moisture content reduced to from 9 to 10 per cent when the material was loosely piled so that air had free access to it. If the changes are produced by enzymes, the enzymes concerned are not destroyed by treatment of the fruit with sulphur dioxide or sodium chloride or by heating it to 80° C. (176° F.) prior to drying.

At relative humidities higher than 80.5 per cent, the absorption of moisture was sufficient to permit rapid and abundant development of molds and yeasts, which destroyed the material within a few months.

Exposure to fumes of sulphur dioxide, immersion in 2 per cent sodium chloride, or heating in steam to 80° C. (176° F.) preparatory to drying, did not prevent the development of discoloration at low humidities or the growth of organisms at the higher humidities, all the lots kept at any given humidity ultimately reaching the condition of the untreated control. Of the various treatments, that with sulphur dioxide retarded the development of these changes somewhat longer than the others. Sodium chloride was next in effectiveness, but its reaction with some constituent of the fruit produced a characteristic alteration of color in some varieties.

The several varieties showed considerable differences in the rate at which deterioration developed, deterioration being most rapid in the variety which combined highest acidity and astringency with lowest content of sugar.

Evaporated apples are highly hygroscopic. Material having 13 to 15 per cent moisture is in approximate equilibrium with the atmosphere over sulphuric acid of 1.30 specific gravity, having an osmotic pressure approximating 750 atmospheres. Fruit having the standard moisture content of 24 per cent is in approximate equilibrium with air of 75 per cent relative humidity at 30° C. (86° F.) and will rapidly absorb moisture when the atmospheric moisture rises above this value.

Adequate protection of evaporated apples against deterioration in prolonged storage involves thorough drying and careful packing of the material and control of the humidity of the storage room. By thorough drying is meant the reduction of contained moisture, not merely to a point at which mold growth can not occur, but to a lower point at which oxidations and other changes not dependent upon the growth of organisms are arrested. Control of humidity in the storage room implies maintenance of atmospheric humidity at or below the point of equilibrium with the material. Careful packing involves the use of the most efficient means of preventing access of atmospheric oxygen to the material.

The temperature of the storage room plays a very significant rôle in determining the rate and extent of deterioration. The present study is not concerned with the effects of storage at various temperatures, all the material having been held at temperatures ranging between 20° and 30° C.

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